

NASA
Engineering Directorate
Materials Science Division
Kennedy Space Center, Florida

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SUBJECT: Post STS-134 Evaluation of Main Flame Deflector Witness Materials

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1. ABSTRACT

NASA and USA design engineers submitted witness materials from the solid rocket booster (SRB) main flame deflector for evaluation after the launch of STS-134. The following items were submitted for analysis: 1018 steel witness rods, 304 stainless steel caps, tungsten pistons, and A-286 piston sleeves. All of the items were photographed in order to document their condition after the launch of STS-134. All of the items were dimensionally measured in order to determine the amount of material lost during launch. Microstructural changes were observed in the 1018 witness rod metallographic samples due to the heat of the launch.

2. FOREWORD

Materials tested on the SRB main flame deflector at Launch Complex (LC) 39A during the launch of STS-134 were submitted for evaluation. The following items were exposed and submitted: 1018 steel witness rods, 304 stainless steel caps, tungsten pistons, and A-286 piston sleeves. The items were exposed at top, middle, and bottom locations. The materials were analyzed in order to determine their suitability for use in the main flame deflector as an alternative to the refractory material currently used on the flame deflector during launch. The purpose of the investigation was to evaluate the condition of the material after being subjected to the plume environment from one launch. The requested analyses included photo-documentation, dimensional measurements, and metallography in order to determine the wear profile and wear mechanism for the different materials. A customer-supplied matrix of the submitted samples and the requested objectives is listed in Table 1. The bottom 304 stainless steel cap was not submitted since no erosion was observed on this sample. Metallography of the 304 stainless steel cap was not requested since the material was determined to have melted in a prior analysis performed after STS-133 (ref. KSC-MSL-2010-0344).

Table 1. Testing matrix and objectives for each of the samples submitted.

Sample Type	Sample Locations	Objective
1018 Witness Rods	Top Middle Bottom	Determine erosion profile Determine if erosion or melting of material occurred
304 Stainless Steel Caps	Top Middle	Determine erosion profile
Tungsten Piston Outer Sleeves	Top Middle Bottom	Determine erosion profile
90-10 Tungsten Pistons	Top Middle Bottom	Determine erosion profile Measure hardness

3. PROCEDURES AND RESULTS

- 3.1 The submitted samples were photographed as-received (Figures 1-11). The severity of erosion varied by sample and by location on the SRB main flame deflector. The tungsten pistons displayed more erosion after STS-134 than in the previous STS-133 launch (Figures 4-6). Both of the 304 stainless steel caps displayed significant material loss (Figures 7 and 8). The customer reported that the Medtherm Calorimeter embedded in the top cap was eroded by the SRB plume at about 1.6 seconds into the event. The Medtherm calorimeter is water cooled and water emitted from the sensor after erosion into the cooling water jacket protected the stainless steel from erosion (Figure 8, arrow). Three piston sleeves were exposed to the launches of STS-133 and STS-134 with corresponding erosion from different orientations (Figures 9-11).



Figure 1. Bottom 1018 witness rod, as-received, profile (left) and top (right). Scale is one inch.



Figure 2. Middle 1018 witness rod, as-received, profile (left) and top (right).
Scale is one inch.

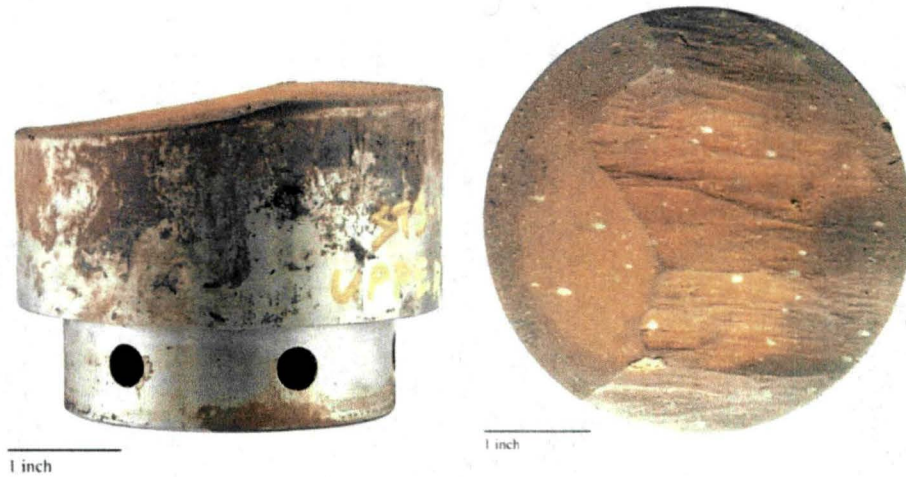


Figure 3. Top 1018 witness rod, as-received, profile (left) and top (right).
Scale is one inch.

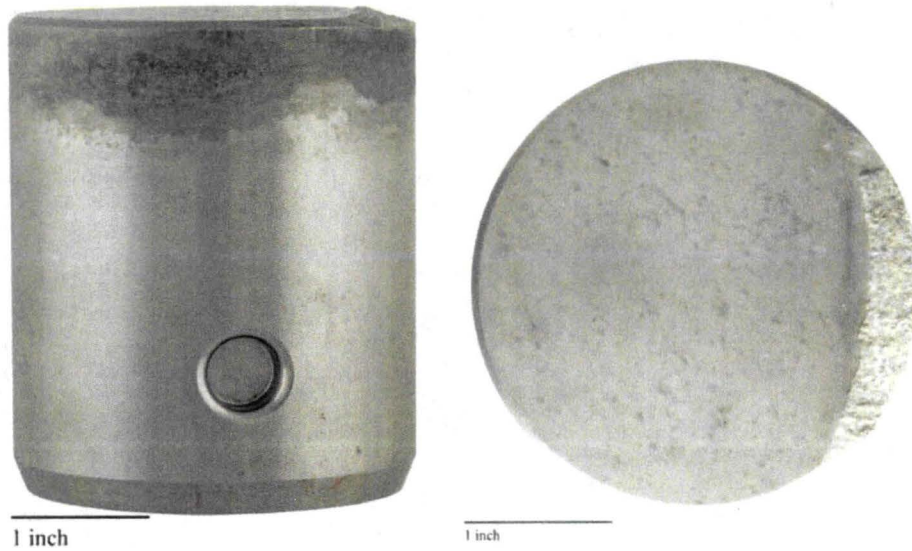


Figure 4. Bottom tungsten piston, as-received, profile (left) and top (right).
Scale is one inch.



Figure 5. Middle tungsten piston, as-received, profile (left) and top (right).
Scale is one inch.

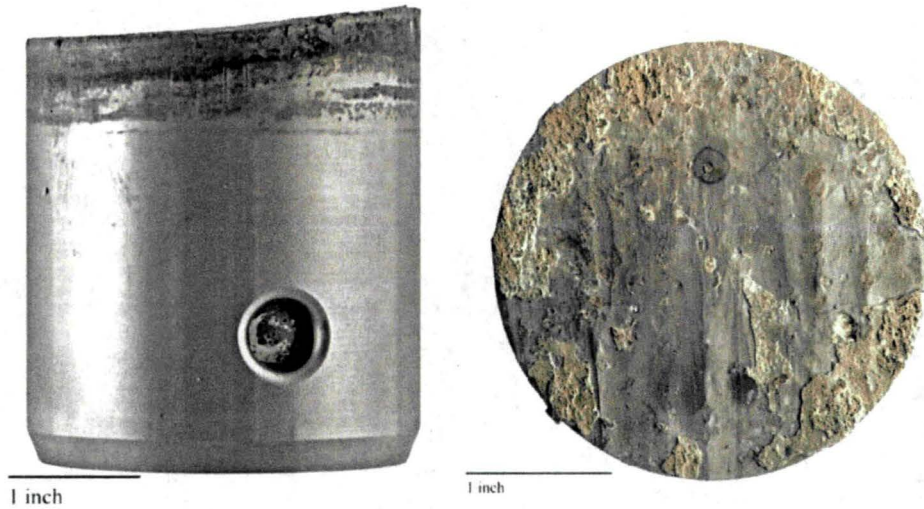


Figure 6. Top tungsten piston, as-received, profile (left) and top (right). Scale is one inch.



Figure 7. Middle 304 stainless steel cap, as-received, profile (left) and top (right). Scale is one inch.

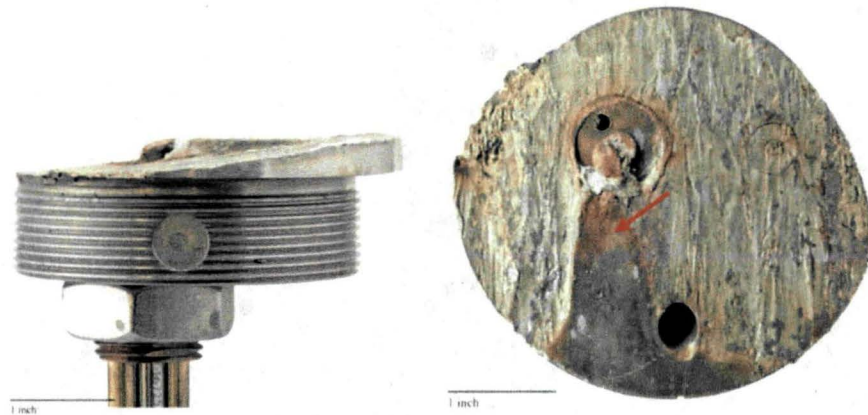


Figure 8. Top 304 stainless steel cap, as-received, profile (left) and top (right). The Medtherm calorimeter is still assembled in this cap. The customer reported that the region with no erosion (arrow) was protected by emission of the Medtherm calorimeter cooling water onto the surface. Scale is one inch.

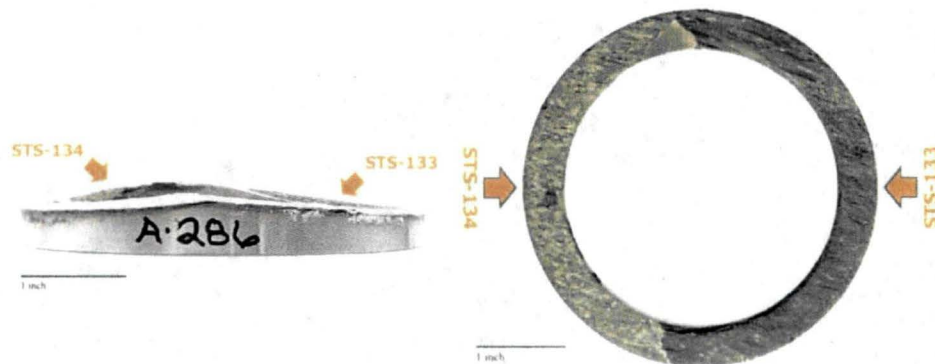


Figure 9. Bottom piston sleeve, as-received, profile (left) and top (right). Scale is one inch.

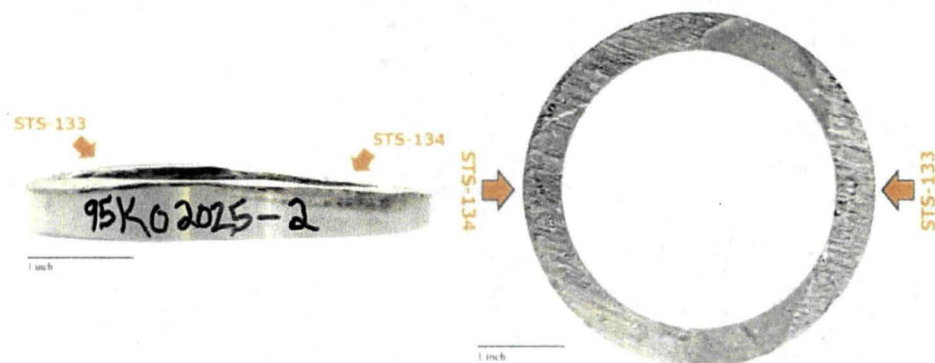


Figure 10. Middle piston sleeve, as-received, profile (left) and top (right). Scale is one inch.

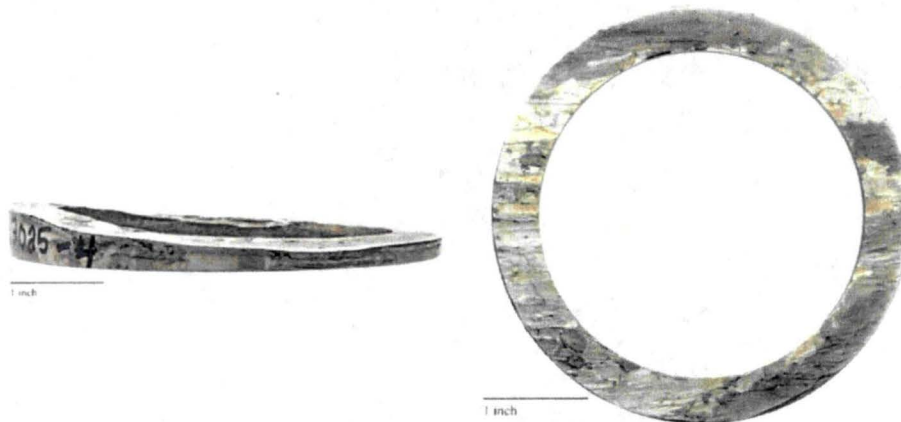


Figure 11. Top piston sleeve, as-received, profile (left) and top (right).
Scale is one inch.

- 3.2 The submitted items were dimensionally characterized in order to determine their erosion profiles. Each of the samples was measured using a Micro-Vu optical coordinate measuring machine (CMM) with an accuracy of ± 0.008 inch. The thicknesses were measured at four places around the periphery of the sample, at the 12, 3, 6, and 9 o'clock positions. The measurements are listed in Tables 2 through 5, along with the average thickness, maximum thickness, minimum thickness, and maximum-minimum difference. All measurements are listed in inches.

Table 2. 1018 Witness Rod Measurements

Measurement Location	Top Sample Thickness	Middle Sample Thickness	Bottom Sample Thickness
12 O'Clock	1.606	2.000	1.914
3 O'Clock	1.798	2.002	1.905
6 O'Clock	1.991	2.003	1.995
9 O'Clock	1.737	2.002	1.847
Average	1.783	2.002	1.915
Maximum	1.991	2.003	1.995
Minimum	1.606	2.000	1.847
Difference	0.385	0.003	0.148

Table 3. 304 Stainless Steel Cap Measurements

Measurement Location	Top Sample Thickness	Middle Sample Thickness
12 O'Clock	0.314	0.307
3 O'Clock	0.024	0.307
6 O'Clock	0.062	0.016
9 O'Clock	0.066	0.311
Average	0.116	0.235
Maximum	0.314	0.311
Minimum	0.024	0.016
Difference	0.290	0.295

Table 4. Tungsten Sleeve Measurements

Measurement Location	Top Sample Thickness	Middle Sample Thickness	Bottom Sample Thickness
12 O'Clock	0.211	0.427	0.416
3 O'Clock	0.445	0.364	0.436
6 O'Clock	0.166	0.527	0.345
9 O'Clock	0.138	0.490	0.390
Average	0.240	0.452	0.397
Maximum	0.445	0.527	0.436
Minimum	0.138	0.364	0.345
Difference	0.307	0.163	0.091
Comment	1 launch	2 launches	2 launches

Table 5. Tungsten Piston Measurements

Measurement Location	Top Sample Thickness	Middle Sample Thickness	Bottom Sample Thickness
12 O'Clock	3.176	3.494	3.496
3 O'Clock	3.193	3.285	3.496
6 O'Clock	3.407	3.498	3.417
9 O'Clock	3.249	3.496	3.495
Average	3.256	3.443	3.476
Maximum	3.407	3.498	3.496
Minimum	3.176	3.285	3.417
Difference	0.231	0.213	0.079

- 3.3. The three 1018 witness rod samples were cross-sectioned at the 12 o'clock positions, mounted in acrylic resin, and prepared for metallographic examination. The three samples showed varying degrees of microstructural changes due to the heating of the metal during launch, followed by quenching due to the water deluge. The heat affected zones in the top and bottom samples at the 12 o'clock position consisted of a transition to untempered martensite with possible minor amounts of bainite at the edge of the samples from the ferrite and pearlite grains in the parent metal (Figures 12, 13, and 14). The heat affected zone in the middle sample at the 12 o'clock position did not display a microstructure that was affected by heat as much as the other two samples. The ferrite and pearlite grains were still present, but additional carbides formed in the microstructure at the surface (Figures 15 and 16). The heat affected zone was approximately 0.08 inch (2 mm) deep in the bottom sample, 0.06 inch (1.5 mm) deep in the top sample, and only 0.008 inch (0.2 mm) deep in the middle sample. High magnification observation at the surface of the witness rod revealed no apparent indications of melted metal, such as dendrites or distorted grains (Figures 14 and 16). The possibility of melting is not likely, but could not be eliminated because the melted metal could have ablated from the surface due to the launch blast.

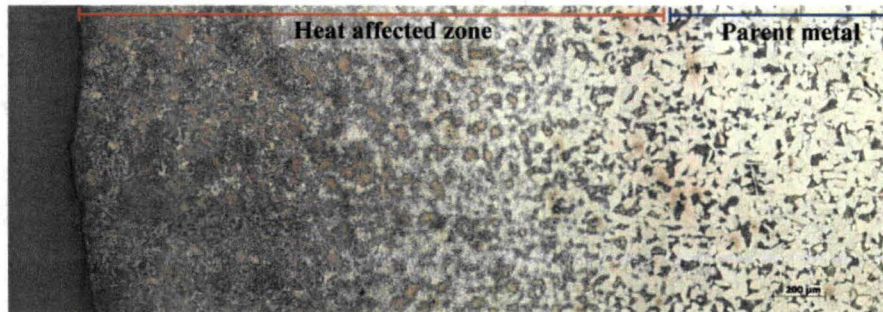


Figure 12. Micrograph of the surface of the bottom sample 1018 witness rod showing martensite with possible minor amounts of bainite in the heat affected zone transitioning to ferrite and pearlite in the parent metal. Note: Surface of the witness rod is on the left. Etchant: 2% nital. Original magnification: 100X



Figure 13. Micrograph of the surface of the top sample 1018 witness rod showing the martensite with possible minor amounts of bainite in the heat affected zone transitioning to ferrite and pearlite in the parent metal. Note: Surface of the witness rod is on the left. Etchant: 2% nital. Original magnification: 100X

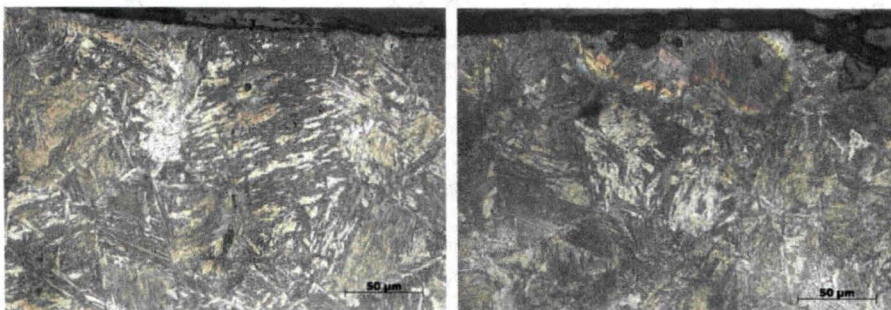


Figure 14. Micrographs at the surface of the bottom sample (left) and top sample (right) showing the untempered martensitic grain structure with possible minor amounts of bainite in these locations. No apparent indications of melting and resolidification of the metal are present. Note: Surface of the witness rod is on the top and discoloration at the edge of the sample is an etching artifact. Etchant: 2% nital. Original magnifications: 500X

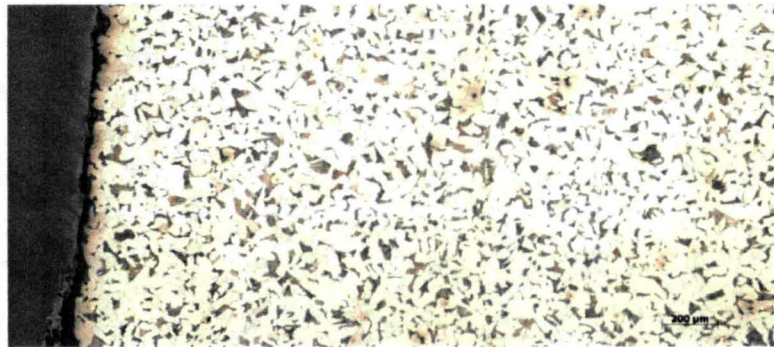


Figure 15. Micrograph of the surface (left) of the middle sample 1018 witness rod showing no change in the microstructure of ferrite and pearlite at the surface. Note: Surface of the witness rod is on the left. Etchant: 2% nital. Original magnification: 100X

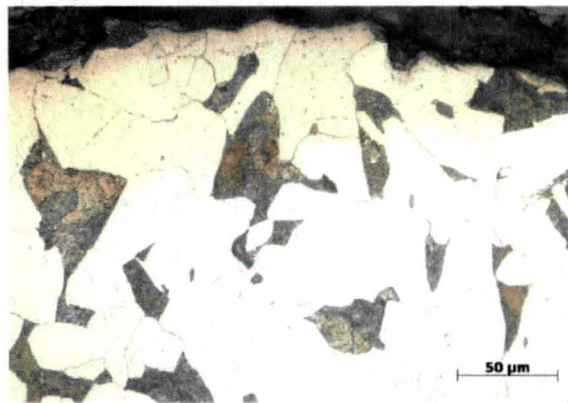


Figure 16. Micrograph at the surface of the middle sample showing the grain structure in this location. No apparent indications of melting and resolidification of the metal are present. Note: Surface of the witness rod is on the top. Etchant: 2% nital. Original magnification: 500X.

- 3.4. In order to confirm the microstructural changes that were observed in the 1018 witness rods, microhardness testing was performed on the metallographic specimens using a Vickers indenter and a 500 g load. The measurements were taken every 0.5 mm, starting near the surface of the witness rod, and the results are shown in Figure 17. The microhardness values were distinctly different in the transformed region versus the parent material. The average microhardness in the heat affected zone was 401 Vickers scale (HV), which converts to 41 Rockwell C scale (HRC), per ASTM E 140, *Standard Hardness Conversion Tables for Metals*. A hardness of 41 HRC is typical for untempered martensite in 1018 steel. The average hardness in the parent metal was 148 HV, which converts to 79 Rockwell B scale (HRB). A hardness of 79 HRB is typical for normalized 1018 steel.

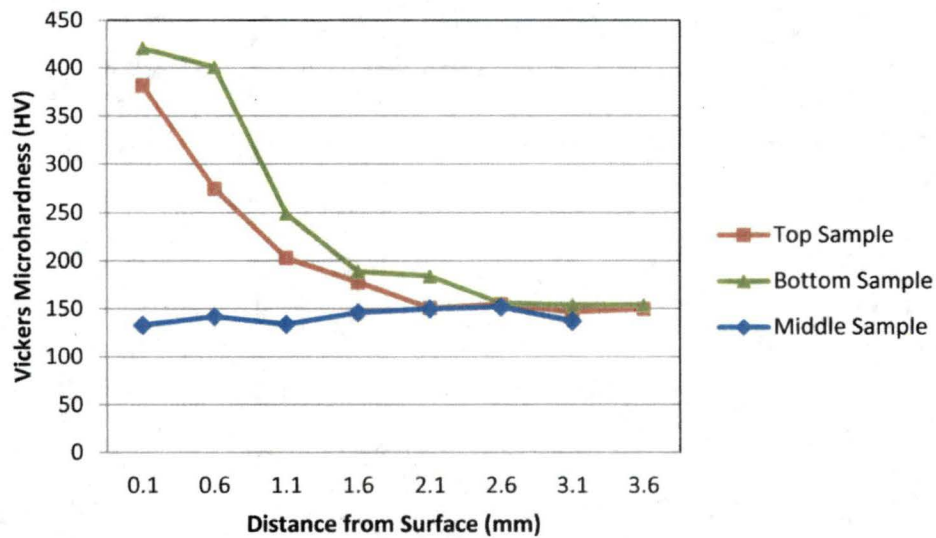


Figure 17. Microhardness values as a function of depth in the 1018 witness rods.

3.5. Hardness measurements were taken per ASTM E 18, *Standard Test Methods for Rockwell Hardness of Metallic Materials*, on the tungsten piston samples in the eroded area and on an undamaged area and are reported in the Rockwell A scale (HRA) in Table 6. The hardness values reported are the average of several trials. In accordance with standard practice, the average hardness is reported to the nearest whole number. The hardness values indicate a minor decrease in the material hardness at the location beneath the most erosion. Due to the geometry of the pistons, these hardness measurements should only be interpreted as relative to each other.

Table 6. Rockwell A Scale (HRA) hardness test results

Tungsten piston	Top	Middle	Bottom
Worst area under the burned surface, tested on the diameter, approx. 1/8—1/4 inch from the burned edge	61	65	64
Clean, undamaged area on the diameter, near the base	63	66	65
Calibration verification: 9/2/2011 Sun-Tec Calibration Standard Test Block, S/N 102722, 64.3 HRA ± 1.0	64.7	64.9	64.9

4. CONCLUSIONS

- 4.1. The 1018 witness rod samples were photographed, measured for dimensional changes, evaluated for microstructural differences, and tested to determine the microhardness profile. The bottom and top witness rod samples had visible erosion occur on the exposed surface of the witness rod. The bottom and top samples exhibited a transformation of the microstructure to untempered martensite in the heat affected zone at the surface of the witness rod due to heating during launch and quenching during water deluge. This transformation was confirmed by a significant increase in the hardness of the heat affected zone compared to the hardness of the ferrite and pearlite grains in the parent metal. The transformed microstructure is difficult to correlate with reference sources due to the severe conditions of launch. The bottom sample had a heat affected zone that was approximately 0.08 inch (2 mm) deep and the top sample had a heat affected zone that was approximately 0.06 inch (1.5 mm) deep. No apparent indications of melting were observed in the microstructure; however, the launch blast could have removed any evidence of melting.
- 4.2. The 304 stainless steel caps and the stainless steel piston sleeves were photographed in order to document their condition after STS-134 and measured for dimensional changes.
- 4.3. The tungsten pistons were photographed in order to document their condition after STS-134 and measured for dimensional changes. Hardness measurements taken on the sample in the eroded area and in an undamaged area indicate a minor decrease in the material hardness at the location beneath the most erosion.

EQUIPMENT: Micro-Vu optical CMM Excel, ECN-2237258
 Zeiss Z1m metallograph, S/N 3837000175
 Struers Duramin microhardness tester, S/N 5640020
 Wilson/Rockwell hardness tester, S/N 81987709

RELATED DOCUMENTATION: KSC-MSL-2010-0344
 ASTM E 140, *Standard Hardness Conversion
 Tables for Metals*
 ASTM E 18, *Standard Test Methods for Rockwell
 Hardness of Metallic Materials*

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